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ADAPTING DECISION MAKING TO UNCERTAINTY WHEN ADDRESSING SEA LEVEL RISE RESPONSE IN PUGET SOUND

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INTRODUCTION

It is difficult for decision makers to deal with scientific uncertainty when making public policy choices. These difficulties become particularly apparent as local jurisdictions begin to address climate change and its related impacts. Preparation and incorporation of climate predictions is hampered by the complex non-linear nature of the climate system and the variability of future climate scenarios. Additionally, the surrounding institutional, legal and policy system is primarily linear. This difference in structure increases the complexity of addressing climate change impacts. Sea level rise in Puget Sound provides a relevant current forum within which to address these issues.

CLIMATE SCIENCE

The Earth's climate system is highly nonlinear with dynamics governed by abrupt changes, multiple equilibria, and thresholds (Rial et al. 2004). These nonlinearities are apparent in the natural climate system as well as the social system and the combined social-ecological system (Folke et al. 2002). Rapid threshold responses in ecosystems at regional scales increase the complexity and difficulty of responding to climate change (Burkett et al. 2005).

Global sea level rise (SLR) is one of the many aspects of climate change. Thermal expansion due to ocean temperature increases and mass input due to melting glaciers and ice sheets are the primary components responsible for sea level rise. Both of these inputs are driven by increases in atmospheric greenhouse gas concentrations, the resultant Earth energy imbalance and subsequent warming (IPCC 2007). Rates of SLR vary on many different scales both spatially and temporally (Church et al. 2004). The long-term average, based on tide gauge records over the last 50 years, is +1.8 $\pm$ 0.3 mm/yr (Nerem et al. 2006). However, this rate has accelerated and the TOPEX/Poseidon and Jason 1 satellite measurements from 1993-2003 provide a value of +3.1 $\pm$0.4 mm/yr (IPCC 2007, Nerem et al. 2006). It is not yet clear whether the rate acceleration reflects a long-term change or decadal variability (IPCC 2007, Nerem et al. 2006).

Predicted changes in global sea level range from 0.18m to 0.59m by 2099 (IPCC 2007). However, these predictions may not be entirely accurate (Rahmstorf 2007). Making prediction of future SLR is difficult because the physical processes which determine the rates of Greenland ice loss and Antarctic ice sheet melting are not completely understood and have not been adequately modeled (Alley et al. 2005). In response to this model uncertainty, Rahmstorf proposes the use of a semi-empirical model which, when applied to the IPCC Third Annual Report emission scenarios, predicts 0.5m-1.4m of sea level rise by 2100 (Rahmstorf 2007). At this point, exact predictions for SLR are not currently possible and regional policy makers are forced to make choices in an uncertain environment. This study uses regionally specific SLR scenarios to investigate the sensitivity of local policies and regulations and identify barriers to adaptation.

RESILIENCE FRAMEWORK

The concept of resilience has evolved beyond the confines of ecological systems where it was first introduced to describe multiple stable state behavior (Holling 1973). Resilience is defined to be "..the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker et al. 2004). The resilience perspective is well suited for approaching complex social-ecological systems characterized by non-linear dynamics, thresholds, and uncertainty across a variety of spatial and temporal scales (Folke 2006).

Sea level rise is a slow ecological variable (occurring over decadal to century time scales). Major storms, with their associated storm surge and flooding, are fast variables (occurring on hourly to daily time scales). The tidal height at the time of the storm is a key factor in determining the inundation and impact of that storm. For example, current levels of coastal protection may be designed to enhance social-ecological resilience to a tidal and storm surge stressor two feet above the ordinary high water. The impacts of this storm will not cause the system to cross a boundary and after the storm, the system will remain in or return to the original state. Increasing sea level by one foot effectively moves the boundary between regimes. In this new configuration, a two-foot storm surge will actually be three feet above the original high water mark and has the potential for substantially greater impacts. If the impact is large enough, the system may not recover and will move across the boundary into a new regime. The interaction between pressures on multiple temporal and spatial scales determines the dynamics of the system and can create non-linear responses (Chapin et al. 2006).

The uncertainties mentioned earlier, the potential non-linear dynamics of the social-ecological systems, and the dependence on human choices, make determination of appropriate sea level rise responses difficult. Focusing on resilience does not attempt to eliminate these uncertainties but to develop better ways to co-exist with inherent and irreducible uncertainties (Klinke & Renn 2002). Considering the scale of the social-ecological system in question is important. The resilience framework can be applied at variety of different scales with differing results (Walker et al. 2004). Resilience can be increased in one of three ways: 1) decreasing exposure, 2) decreasing sensitivity, or 3) increasing adaptive capacity.

In the case of sea level rise, decreasing exposure is tied to mitigation actions that limit the long-term effects of climate change and decrease sea level rise. Decreasing sensitivity is tied to actions taken in the coastal zone (land use planning, building codes…etc.) that provide short and long-term protection to current infrastructure or ecosystems. Finally, the adaptive capacity of a system is determined by the ability of the system to self organize and learn from experience (Folke 2006). Increasing adaptive capacity allows the social-ecological system to respond to stressors and increases adaptation. The focus of this study is on adaptation because it is local (or regional) in scale (Füssel & Klein 2006) and can be effectively pursued by local governments and institutions.

PRELIMINARY INVESTIGATION

The choice of Puget Sound is useful for a number of reasons. First, it provides a local context in which to explore resilience and adaptation. Second, King County and the City of Seattle (as well as many other communities) are currently in the process of updating their Shoreline Master Programs (SMP). SMPs are designed to balance utilization and protection of the State's "valuable and fragile" natural shoreline resources (RCW 90.58.020). This, along with discussion of improvements to Seattle's waterfront, has provided an avenue for discussion of SLR policy.

The first phase of this study is designed to identify the potential impacts of a variety of SLR scenarios. Given the large amount of uncertainty associated with future SLR, this study does not attempt to predict SLR or determine the upper or lower limits of SLR within a particular timeframe. The scenarios are merely illustrative and highlight the necessity of policy discourse on the issue. Geographic information system (GIS) maps were created for selected regions of Puget Sound. The LIDAR based digital elevation maps (DEMs) have a vertical error < 2ft (Finlayson 2005). This level of accuracy allows for consideration of potentially real, non-catastrophic, SLR scenarios. The current shoreline for the maps was determined based on NOAA Tidal benchmark data (NOAA 2007) and an approximation for the Ordinary High Water (OHW) line. OHW lies at a variable height above Mean Higher High Water, generally in the range of one to two or more feet above Mean Higher High Water depending on fetch, exposure, and location within Puget Sound. The selection of 1.25 feet is simply judgment (based on the field experience of Canning); others may differ. Orthophotos were placed over the DEM to provide visual references and highlight the areas of vulnerability.

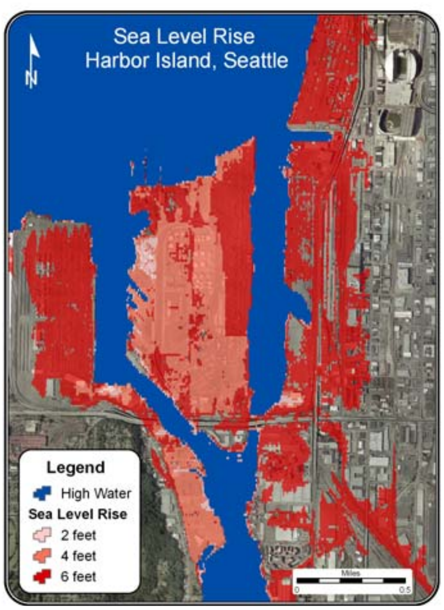

Figure 1. Preliminary Map of Possible SLR Scenarios for Harbor Island, Seattle

Figure 1 emphasizes the potential vulnerability of low-lying infrastructure, such as the Port of Seattle. It does not model the dynamic processes of on-going historic coastal erosion and bluff landsliding caused at least in part by historic sea level rise. It depicts three simple inundation scenarios based solely on elevation data. In reality, SLR will not be experienced by gradual increases in mean sea level, but by increasing frequency and magnitude of coastal erosion events, as well as increasing flood frequency as formerly extreme events become more common with rising sea levels.

The second phase includes a review of the legal and regulatory framework available for response and adaptation in Washington State. This investigation was designed to consider not only the adaptive potential for individual laws, but also the interactions between multiple laws that create potential barriers or opportunities to address sea level rise. The laws considered include: National Flood Insurance (42 USC 4001), Washington Shoreline Management Act (RCW 90.58), Washington Growth Management Act (RCW 36.70A), and Washington Flood Plain Management Act (RCW 86.16).

Preliminary analysis highlights a number of potential opportunities for addressing SLR. These opportunities include using the SMP requirements to create shoreline designations and protect ecological functions to wrap consideration of SLR into current planning processes. A similar potential exists within the current flood ordinance and regulations however, complications arise with floodplain designations and update frequency. This analysis will identify key barriers and opportunities for increasing the adaptive capacity and thus resilience of the system.

CONCLUSION

Though still in a preliminary stage, this study has identified a number of key issues related to addressing sea level rise in Puget Sound. The uncertainties associated with climate change and sea level rise make it difficult for policy makers to use their normal tools when approaching this problem. The use of a resilience framework and a focus on increasing adaptive capacity in response to the variety of potential sea level rise scenarios is a promising approach. Creation of detailed local sea level rise maps can be a useful tool in the public policy debate. An analysis of the legal framework surrounding potential responses serves to identify key opportunities and barriers that should be considered when designing policy responses to increase social-ecological resilience.

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